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Evaluation of a Survey Method for Estimating Number and Monitoring Occupancy of Bald Eagle Nests in Kenai Fjords National Park

Natural Resource Technical Report NPS/SWAN/NRTR—2009/271

ON THE COVER
Bald eagle in an incubating posture on a nest in Pederson Lagoon, Aialik Bay.
Photograph by: Bill Thompson, NPS-SWAN

Evaluation of a Survey Method for Estimating and Monitoring the Number of Active Bald Eagle Nests in Kenai Fjords National Park

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Abstract

The Southwest Alaska Network (SWAN) is monitoring the condition of key natural resources or "vital signs" in five national park units in southwest Alaska, including Kenai Fjords National Park (KEFJ). Bald eagles were selected as a vital sign because of their important ecological role in freshwater and marine coastal systems. The proposed monitoring objectives are to estimate long-term trends in nest occupancy and productivity of bald eagles in SWAN parks. In KEFJ, bald eagle nest surveys have not been conducted since 2002 and previous surveys, which were primarily boat- and ground-based, did not incorporate a sightability correction. The U. S. Fish and Wildlife Service (USFWS) recently proposed a double-observer method for surveying bald eagle nests that provides a sightability correction for nests that are missed. Another component of the USFWS design requires an up-to-date list of previously located eagle nests within the area of interest. An evaluation of the feasibility for adopting this design to monitor nesting bald eagles in KEFJ would require an updated map of nest locations. Therefore, the primary objectives of this study were to produce an updated map of active and empty nests along the coastline and in nearby inland areas of KEFJ, field-test the double-observer portion of USFWS protocol, generate a sightability adjusted estimate of the number of active nests along the coastline and in nearby inland areas of the park, and estimate how much of the park's coastline and nearby inland areas could be feasibly surveyed for nests via helicopter under existing cost and logistical constraints. Observers detected 44 active nests with incubating adults or eggs and 36 nests that were empty during the seven-day survey that covered approximately 500 mi (800 km) of park coastline. Thirty-seven of the active nests were in Sitka spruce, four were in mountain hemlock, two were on the ground and one was in a balsam poplar. Thirty-three of 44 (75%) active nests were within 65 ft (20 m) of the shoreline (maximum distance = 1680 ft [512 m]). The clearly best supported double-observer model included a time-of-day covariate and estimated the number of active nests to be 65 (95% Bayesian credible interval: 50, 101). The time-of-day covariate likely helped account for heterogeneity in sighting probabilities induced by observer fatigue and lighting/shadow conditions that occurred both during early morning and late afternoon. As the next steps in field testing and evaluation, we recommend 1) using simulations to obtain a preliminary estimate of the minimum size and number of park coastline segments that should be randomly sampled to meet monitoring objectives and 2) performing nest surveys within randomly chosen coastline segments to evaluate survey precision, costs and logistical constraints that will help inform the design for monitoring nest occupancy of bald eagles along the coastline and in nearby inland areas of KEFJ.

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We thank P. Schempf (U.S. Fish and Wildlife Service), M. Swaim (U.S. Fish and Wildlife Service), and B. Mangipane (Lake Clark National Park and Preserve) for their review comments that greatly improved this report. Many thanks to M. Kansteiner (KEFJ) for providing logistical support during our surveys. J. Cusick (National Park Service – Alaska Regional Office) provided invaluable assistance by providing the data dictionary and Trimble JunoSB used in data collection, and creating the file geodatabase for the survey data. We thank C. Redd of Pollux Aviation for his excellent piloting skills and great attitude. J. A. Royle (U.S. Geological Survey) graciously provided analysis advice and the R2WinBUGS code that we modified for fitting the Bayesian hierarchical models. We greatly appreciate the invaluable help of J. Schmidt (National Park Service – Central Alaska I&M Network) with modifying the R2WinBUGS code and with analyzing the data. This project was funded by the National Park Service - SWAN I&M Program, and logistical and staff support were provided by Kenai Fjords National Park.

Introduction

Bald eagles (*Haliaeetus leucocephalus*) are keystone predators on avian (e.g., seabirds) and fish (e.g., salmon) populations and hence serve an important ecological role in freshwater and marine coastal systems in national parks within the Southwest Alaska Network (SWAN; Figure 1) of the National Park Service (NPS). Three of these parks, Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), and Lake Clark National Park and Preserve (LACL), contain large breeding populations of bald eagles. Nonetheless, bald eagle populations in general are under continuing threat from human-related impacts such as ecotourism, sport and commercial fishing, timber harvest, potential mining activities adjacent to the parks, and potential oil spills or other accidents along marine coastlines (Buehler 2000). Further, global climate change will have an unknown effect on their forage base and nesting habitat (e.g., see Agler et al. 1999). Consequently, bald eagles were selected as a vital sign to monitor in SWAN parks and this vital sign was rated as *highly desirable* in the prioritization process (Bennett et al. 2006).

Annual surveys of nest occupancy and productivity are commonly used to monitor raptor populations, including bald eagles (Fuller and Mosher 1987). However, bald eagles may not attempt to nest or their attempt may fail if breeding conditions are unsuitable during a given year. Their occurrence and reproductive performance may be influenced by toxic contaminants, food availability, human-related impacts, and climate (Buehler 2000). Thus, their nest occupancy and reproductive rates may be useful indicators of both current condition and long-term change of freshwater and marine coastal systems.

In KEFJ, park staff performed surveys of bald eagle nests during 1986-2002, but only surveys during 1990-2002 followed a standard protocol. Both spring occupancy and summer productivity surveys were conducted primarily on the ground (accessed via boat) during these years. In addition to lacking a correction for nests that were missed, these surveys required staff to climb steep slopes to view contents of detected nests, which raised serious safety concerns. Moreover, extreme wind conditions that commonly occur along this coastline preclude the safe use of fixed-wing aircraft at altitudes necessary to effectively survey bald eagle nests.

The U.S. Fish and Wildlife Service (USFWS) recently proposed a dual-frame sampling design (Haines and Pollock 1998) that incorporates a double-observer component (Nichols et al. 2000) that adjusts for nests that are missed during surveys (U.S. Fish and Wildlife Service 2007). The dual-frame aspect of this design requires an up-to-date list of previously located eagle nests, which includes both active (incubating adult) and empty nests, within the area of interest (i.e., list frame). Moreover, these list-frame nests should comprise at least 40% of all available nests to realize the gains in efficiency from the dual-frame approach (U.S. Fish and Wildlife Service 2007). These data are combined with new nests detected from (usually) a random sample of plots or quadrats within the area of interest (i.e., area frame). An evaluation of the feasibility for adopting this design to monitor nesting bald eagles in KEFJ would require an updated map of nest locations. Therefore, the primary objectives of this study were to produce an updated map of active and empty nests along the coastline and nearby areas of KEFJ, field-test the double-observer portion of USFWS protocol, generate a sightability adjusted estimate of the number of active nests along the coastline and nearby areas of the park, and estimate how much of the

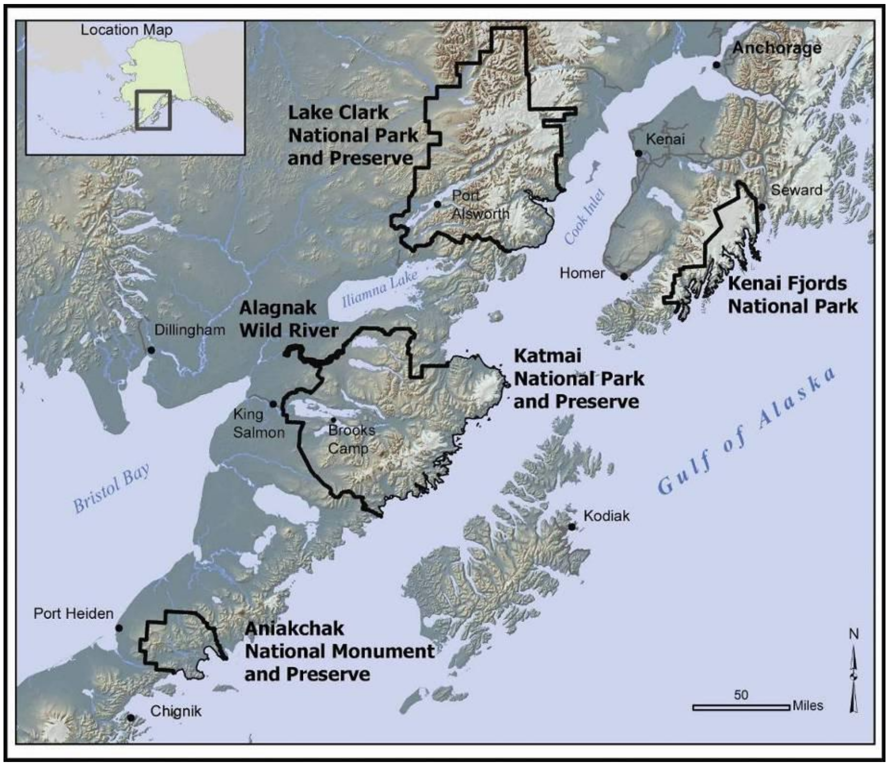

Figure 1. The five national park units within the Southwest Alaska Network (figure from Bennett et al. 2006).

park's coastline and nearby inland areas could be feasibly surveyed for nests via helicopter under existing cost and logistical constraints.

Methods

Study Area

KEFJ is a 1,047 mi^2 (2,712 km^2) park located on the southeastern coast of the Kenai Peninsula in southcentral Alaska (Figure 1). The park contains approximately 500 mi (800 km) of coastline that is characterized by steep mountains reaching over 5,000 ft (1,500 m) from sea level, deep-water fjords, a rocky and convoluted shoreline, and tidewater glaciers. Half of the park is covered in glaciers. Average annual precipitation along the coast is estimated by PRISM models to range between 50 - 100 in (127-254 cm; Lindsay and Klasner 2009), which helps support the Sitka spruce (*Picea sitchensis*) - mountain hemlock (*Tsuga mertensiana*) forest community.

Aerial Survey and Data Entry

We used an R44 Clipper II helicopter with fixed floats (Figure 2), operated via contract with Pollux Aviation, to conduct bald eagle nest surveys in non-glaciated portions of the coastline and nearby inland areas of KEFJ during 14-19 May 2009. Off-shore islands are not administered by NPS so were not included in the survey, with the exception of Striation Island in Northwestern Fjord and Slate Island in Aialik Bay. The survey period was chosen based on nest initiation data collected on >1400 bald eagle nests sampled in Prince William Sound, Alaska (USFWS, P. Schempf, Wildlife Biologist, unpublished data). An R44 Clipper I with pop-out floats was used to conduct surveys on 13 May, but we switched to a Clipper II with fixed floats for the remainder of the survey period because of its larger payload (hence longer flight time before refueling) and

Figure 2. The R44 Clipper II helicopter with fixed floats that was used to conduct bald eagle nest surveys in Kenai Fjords National Park during 14-19 May 2009. An R44 Clipper I (not shown) was used for surveys performed on 13 May 2009.

The increased safety factor of fixed floats when flying at low altitudes. We flew surveys at speeds of 20-40 knots (37-74 km per hour) and at altitudes of 400-600 ft (122-183 m); we flew just off-shore when surveying the coastline, just off the forest edge when surveying wide coastal watersheds and nearby lakes, and up the middle (both directions) of narrow coastal watersheds. Seward airport (60º07'36.98N, 149º25'07.72W) was the base of flight operations; Homer airport (59º38'44.00N, 151º28'35.70W) was used for refueling when surveying the southern end of the park.

We used a double-observer method (Nichols et al. 2000), which is a form of mark-recapture, for recording detected nests that adjusted for nests that were missed. Front- and rear-seat observers on the left-hand side of the helicopter (Figure 3) performed independent counts of nests during survey flights. Each observer waited until the nest was beyond the view of the other before announcing that it had been detected. A nest detection was only recorded after it was reconciled by both observers, and these detections were assumed to be independent between observers (see Discussion). The front-seat observer had a wider field of view, and hence a longer time to view a given stretch of habitat, but both observers surveyed the same area. We used standard encounter history format for two sample "occasions" in a mark-recapture context (White 2008) to record which observer detected the nest, where "10" indicated the nest was only detected by the front-seat observer, "01" meant only the rear-seat observer detected the nest and "11" indicated both observers detected the nest. There were a few instances when the pilot detected a nest that was missed by both observers; in these cases the encounter histories were recorded as "00"s (see Data Analyses).

Once a nest had been detected, we recorded various attributes associated with it (Table 1), both entered electronically on a Trimble GPS JunoSB (rear-seat observer) and on hardcopy data forms (front-seat observer; Figure 3). J. Cusick (NPS-AK Regional Office) created a data dictionary for use on the Trimble JunoSB. The Trimble JunoSB was used to record the GPS coordinates (NAD83 Datum) of each nest while the helicopter hovered high above it. The Trimble unit additionally recorded the date, time, vertical and horizontal precision, Max PDOP, Max HDOP, and correction (if any). We used a Nikon D300 digital SLR with a Nikon 80-400mm f/4.5-5.6D ED Autofocus VR Zoom Nikkor lens to take multiple digital photos of each nest to be used as visual aids for relocating the nest in future surveys. A Nikon GP-1 GPS accessory was attached to the camera to geotag each image with the photographer's location.

A Garmin GPSMap 76CSx was used during aerial surveys to collect a track file of continuous GPS locations, spaced at 1-second intervals, to document flight lines. We also used the Garmin unit to record GPS coordinates of empty nests with no adult eagles present because the data dictionary on the Trimble GPS JunoSB only had an entry for empty nests with one adult nearby (Table 1). Further, the Garmin served as a back-up for recording nest coordinates when the Trimble GPS JunoSB could not lock on to enough satellites to register a location at the default level of accuracy. External antennae were attached to both the Garmin and to the Trimble units to increase accuracy of GPS coordinates. We used clear packaging tape to temporarily attach the external antennae to the interior ceiling window of the R44 helicopter (Figure 4). This tape allowed light to come in and did not leave a glue residue on the window.

Table 1. Data collected at each nest detected during the aerial surveys of bald eagle nests conducted in Kenai Fjords National Park during 13-19 May 2009. A revised data form for use in future surveys is in Appendix A.

Nest Attribute[1]	Codes	Description
Nest ID code	*NO*- ("*NO*rth"; mainland coast from Aialik Cape to Bear Glacier) *AI*- ("*AI*alik Bay"; mainland coast from Aligo Point to Aialik Cape) *NW*- ("*N*orth*W*estern Fjord and Harris Bay"; mainland coast from Surok Point to Aligo Point) *OU*- ("*OU*ter coast"; mainland coast from east end of McArthur Pass [south end of Chance Cove] to Surok Point) *NU*- ("*NU*ka Bay and McArthur Pass"; mainland coast from Yalik Point to east end of McArthur Pass [south end of Chance Cove])	A unique alphanumeric code whose prefix refers to a specific bay, fjord or stretch of mainland coast. The general format is "Prefix-#," e.g., the first 3 nests recorded within Aialik Bay were assigned Nest ID codes of AI-1, AI-2, and AI-3, respectively.
Nest latitude/longitude	Decimal degrees (NAD83)	Latitude and longitude of nest location. Time was recorded on hardcopy data forms and later converted to the corresponding GPS coordinates from the Garmin or Trimble unit.
Nest substrate	S (Spruce), H (Hemlock), P (Pine), C (Conifer), D (Deciduous), G (Ground), NA (Not Applicable)	Tree species or substrate where the nest is located.
Nest condition	I (Incubating), E (Empty - 1 Adult Nearby), O-NM (Occupied - Fresh Nest Material), O-2 (Occupied - 2 Adults), 1-E (1 Egg), 2-E (2 Eggs), 3-E (3 Eggs), 1-Y (1 Young), 2-Y (2 Young), 3-Y (3 Young)	Status of detected nest. We did not distinguish between empty and occupied nests when entering data during the survey, but collected the requisite information for all codes shown here.
Eagle age	A (Adult), I (Immature), U (Unknown)	Age(s) of bald eagle(s) sighted at or around a nest. Individuals with predominantly white heads are considered adults.
Eagle behavior	N (Nesting), F (Flying), P (Perching), NA (Not Applicable)	Behavior(s) of the bald eagle(s) at or around a nest.

[1] A "Comments" column was included on the hardcopy data form for recording additional information on nests not covered by the listed nest attributes.

Figure 3. The rear-seat observer holding a Trimble GPS JunoSB that was used to enter data collected during aerial surveys of bald eagle nests in Kenai Fjords National Park during 13-19 May 2009. The front-seat observer is preparing the hardcopy data forms for the survey. The helicopter shown here is an R44 Clipper I, which was only used to conduct surveys on 13 May 2009 (see text for details).

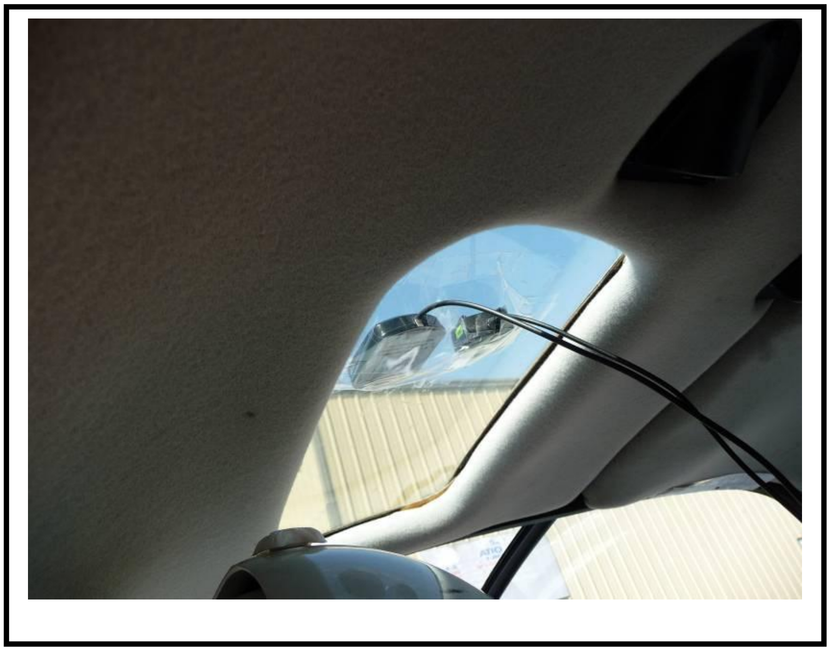

Figure 4. External antennae of the Garmin GPSMap 76CSx (left) and Trimble GPS JunoSB (right) taped to the interior ceiling window of an R44 helicopter that was used during aerial surveys of bald eagle nests in Kenai Fjords National Park during 13-19 May 2009.

Post-processing of Aerial Survey Data

At the end of each survey day, we downloaded GPS data (.ssf) files from the Trimble JunoSB GPS, tracklog (.gpx) files from the Garmin GPSMap 76CSx, and the nest photographs (.jpg and .nef) from the Nikon D300. We used GPS Pathfinder Office 4.1 (Trimble Navigation Ltd., Sunnyvale, CA) to export Trimble GPS data in ESRI shapefile format. Trimble GPS data was not differentially corrected. We used DNRGarmin 5.4 (Minnesota Department of Natural Resources, St. Paul, MN) to export Garmin GPS data in ESRI shapefile format. Spatial data were based on the North American 1983 geographic coordinate system and the North American Datum 1983 Alaska Albers projected coordinate system. Shapefiles were merged and brought into ArcGIS 9.3 (ESRI, Inc., Redlands, CA) for editing and basic analyses.

Because the accuracy of coordinates recorded at nests depended on the number of satellite signals received by the GPS units, we used IKONOS imagery, oblique digital photos and expert judgment to manually adjust these locations. We then used these adjusted locations to estimate elevation, slope and distance to nearest shoreline for each nest. We used the *Extract Values to Points* tool in Spatial Analyst (ArcGIS 9.3; ESRI, Inc., Redlands, CA) to derive elevation and the *Slope* tool to estimate slope from an IKONOS 98 ft (30 m) Elevation Relief Model. The *Measure* tool was used to manually calculate the distance from the adjusted nest location to the nearest shoreline. Null values (0 ft) were changed to 3ft (1 m).

Data Analyses

We used MS Excel to generate summary statistics for various nest attributes. We then constructed a candidate set of mark-recapture models with various individual covariates (factors) thought to affect heterogeneity in sighting probabilities of active nests. These factors included time of day the active nest was detected (PDay; percent [%] of 24 hours) and position of the active nest in the tree (TreeP; top quarter or ground, lower than top quarter; Buehler 2000). Time of day was included to address within-day observer fatigue and effects of lighting (shadows) during the early morning and late afternoon; nearly all survey days were clear and sunny. Position of the active nest in the tree relative to the top (or on the ground) was thought to influence difficulty of spotting the nest. An intercept-only (null) model was included in the candidate set; this model represented the typical mark-recapture (Lincoln-Petersen) estimator that was unadjusted for heterogeneity in sighting probabilities. We originally were going to include survey day as a random effect (Bolker et al. 2009), but sparse data precluded a reasonable fitting model (see Discussion). Thus, we added a candidate model containing an overdispersion term (Resid) to account for extra variation instead (McCarthy 2007).

We employed a Bayesian hierarchical modeling approach with data augmentation (Royle 2009) to fit the double-observer data and covariates, and used the DIC model selection criterion (Spiegelhalter et al. 2002) to choose the best supported model for estimating the number of active nests in the park. DIC can be interpreted similarly as AIC, so a model with a ΔDIC (i.e., the difference between the lowest observed DIC and a given model's DIC) of >10 indicated that it had little empirical support (Burnham and Anderson 2002).

Our implementation of this Bayesian modeling approach differed slightly from previous ones because we also included two nests that were missed by both observers (i.e., "00" observations). We did this by ensuring these two nests were part of each Markov Chain Monte Carlo (MCMC) sample by assigning an MCMC sample probability of 1 to each nest (U.S. Geological Survey, J.

A. Royle, Biometrician, pers. commun). We modified the R2WinBUGS (Sturtz et al. 2005) code provided by Royle (2009) and ran it through freeware programs R (R Development Core Team. 2009) and WinBUGS (Lunn et al. 2000) to fit the Bayesian models (Appendix B). Model convergence and fit were evaluated based on the Gelman-Rubin statistic (Gelman and Rubin 1992, Brooks and Gelman 1998), visual inspection to assess proper convergence in the MCMC chains, and confirming an adequate number of effective parameters had been used.

Results

The bald eagle nest survey required 39.2 hours of flight time over a 7-day period to cover the entire coastline of Kenai Fjords National Park (Figure 5). About 12 hours (31%) of this time was spent on refueling runs to either Seward or Homer. The total cost of the survey was $30,000.

We detected 44 active nests with incubating adults or eggs and 36 nests that were empty within approximately 500 mi (800 km) of park coastline (Figure 5). Thirty-seven of the active nests were in Sitka spruce, four were in mountain hemlock, two were on the ground and one was in a balsam poplar. Thirty-three of 44 (75%) active nests were within 65 ft (20 m) of the shoreline (maximum distance = 1680 ft [512 m]). Active nests occurred on average slopes of 20 deg (maximum = 50 deg) and at average elevations of 47.5 ft (14.5 m; maximum = 425 ft [130 m]). The results from this survey have been incorporated into NPS Theme Manager (Figure 6), which is a tool for organizing, managing, and presenting large amounts of GIS data to users. The survey data and metadata reside in a file geodatabase, including digital photographs hyperlinked to each nest location (Figure 7).

The clearly best-supported model based on ΔDIC included a time-of-day covariate and estimated the number of active nests to be 65 (95% Bayesian credible interval: 50, 101) (Table 2). There was a 95% chance that the true number of active nests was between 50 and 101, and an 80% chance that the true number was between 54 and 86. The estimated average detection probability for the front-seat observer was 0.54 (SD=0.11), whereas it was 0.29 (SD=0.08) for the rear-seat observer.

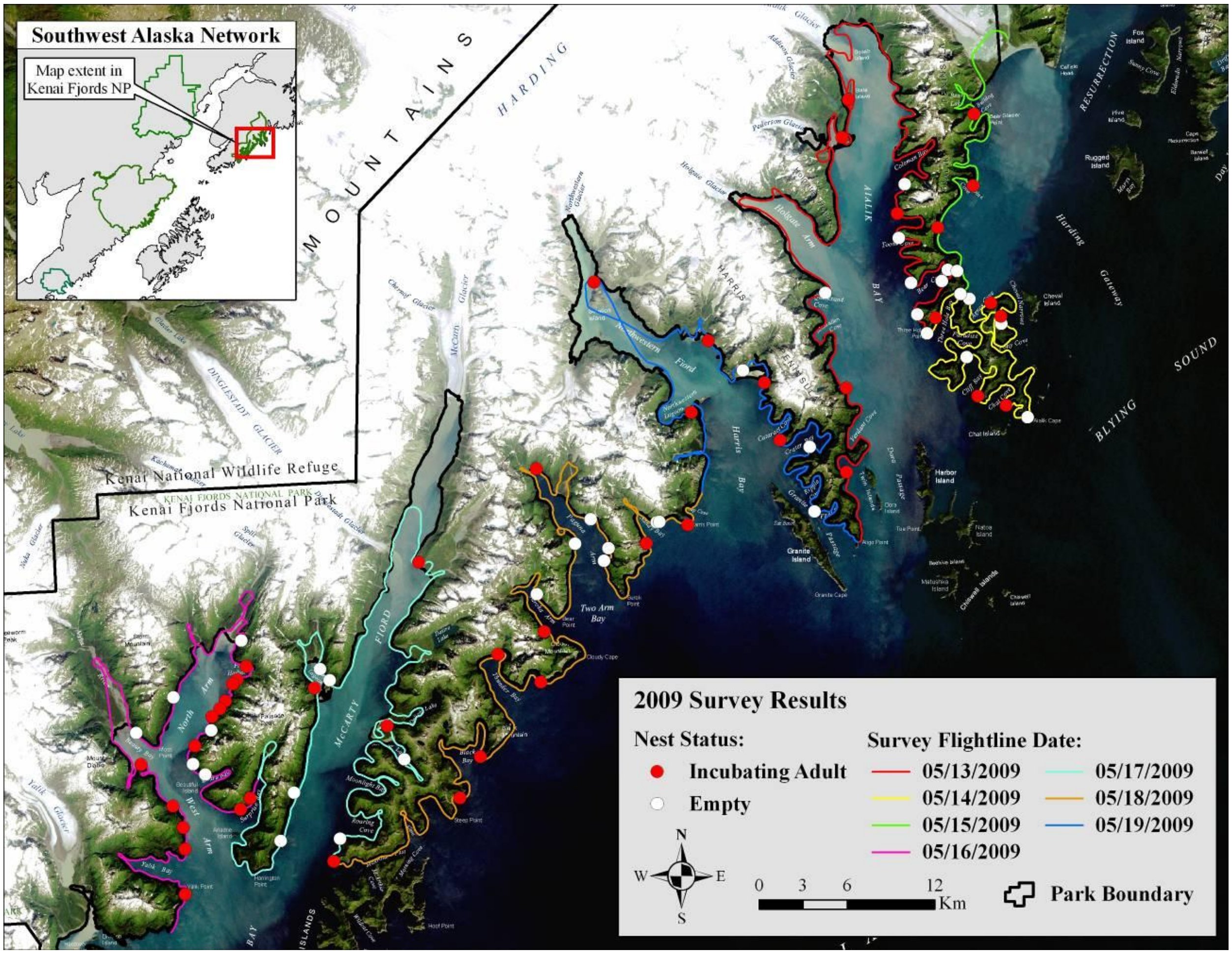

Figure 5. Locations of active nests (incubating adults or eggs; red circles) and empty nests (white circles) of bald eagles sighted during aerial surveys in Kenai Fjords National Park during 13-19 May 2009. Flight lines are color-coded by date of flight. The southernmost extent of the park-wide survey was Yalik Point (southern end of purple flight line) and the northernmost extent was Bear Glacier (northern end of green flight line). The white areas, other than circles, are glaciers. Thus, nesting habitat for bald eagles in the park is restricted to a narrow band of coastline and nearby inland areas.

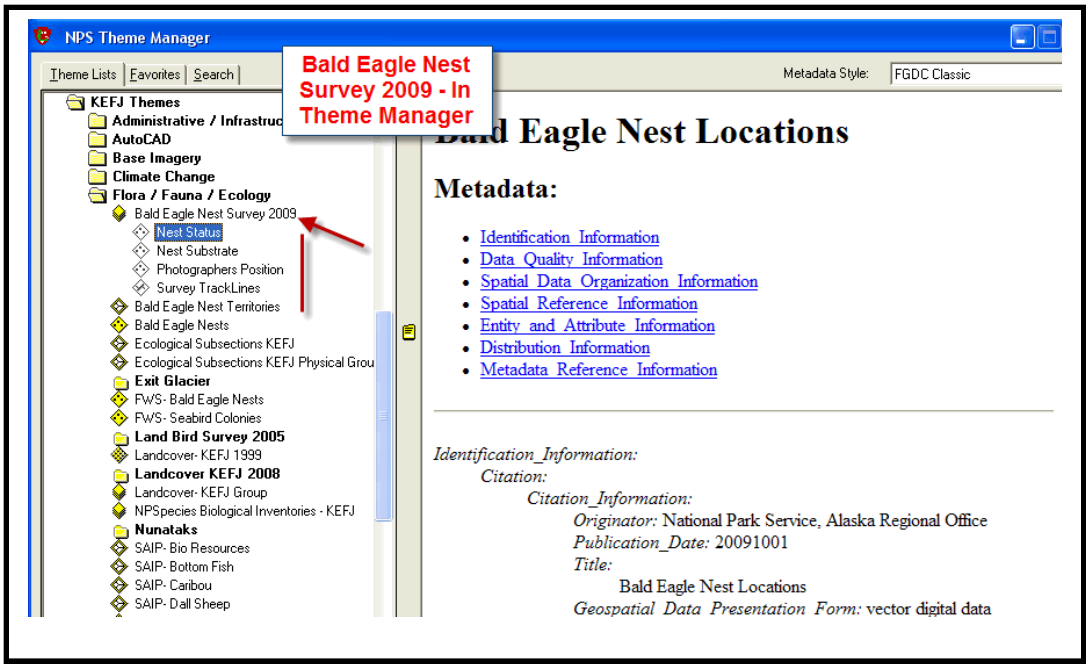

Figure 6. Screen capture portraying the NPS Theme Manager and data from the bald eagle nest survey in Kenai Fjords National Park during 13-19 May 2009.

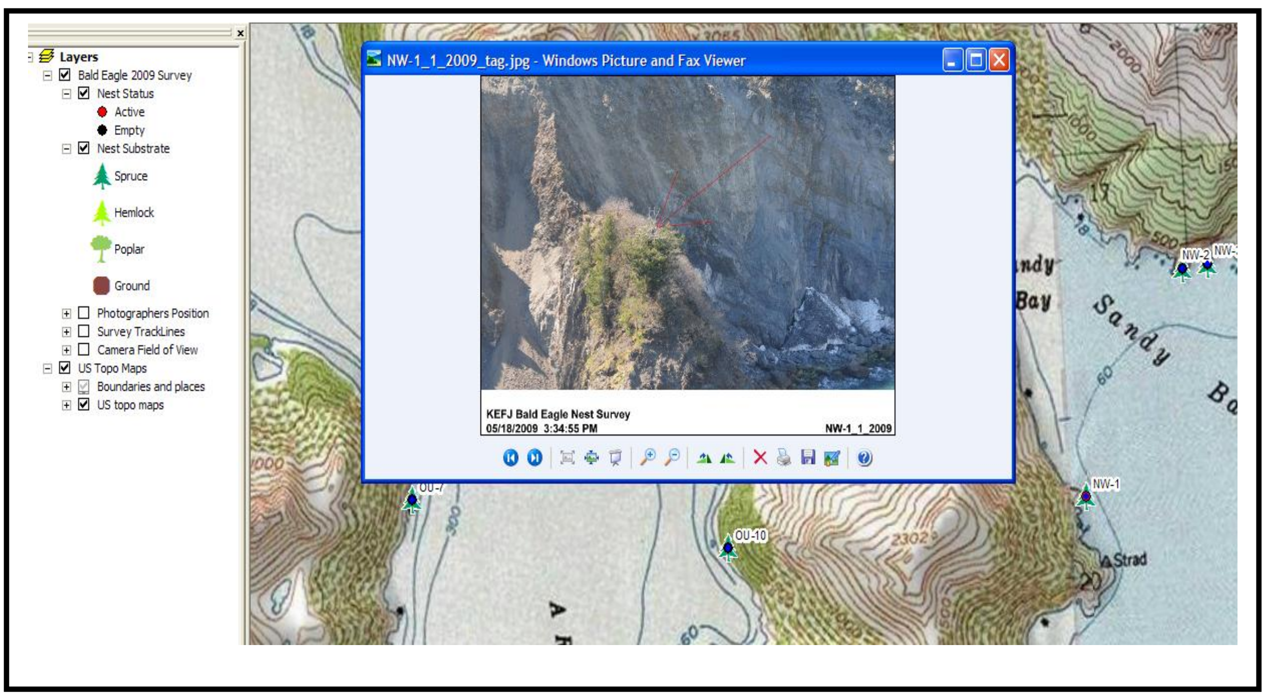

Figure 7. Screen capture showing a hyperlinked photograph of bald eagle nest (ID number NW-1) that was detected during a survey in Kenai Fjords National Park during 13-19 May 2009. A red arrow was added to each photograph to indicate the location of the nest.

Table 2. Model selection results based on DIC for the candidate set of Bayesian hierarchical models fitted to the double-observer counts of bald eagle nests in Kenai Fjords National Park during 13-19 May 2009.

Model	pD[1]	Deviance[2]	ΔDIC[3]
PDay	335.3	91.9	0
Intercept only	325.8	169.9	68.5
Resid	352.5	176.5	101.8
PDay, TreeP, Resid	412.9	165.3	151.0
TreeP	447.5	241.9	262.2

[1] Estimated effective number of model parameters.
[2] Deviance at the mean of the posterior distribution.
[3] Lowest DIC = 427.2.

Discussion

Results of this study allowed us to meet our primary objectives of producing an updated map of active and empty nests in non-glaciated portions of the coastline and nearby inland areas KEFJ, field testing the double-observer portion of USFWS protocol, generating a sightability adjusted estimate of the number of active nests along the park's coastline and nearby inland areas, and estimating how much of the park's coastline and nearby inland areas could be feasibly surveyed for nests via helicopter under existing cost and logistical constraints. Additional fine-tuning will be required as the survey protocol moves forward. For instance, we have refined the data form (Appendix A) so that it better reflects covariates that may be useful for fitting the double-observer model.

A helicopter survey of the non-glaciated portions of the park coastline and nearby inland areas enabled us to produce an updated map of the minimum number of active bald eagle nests in these areas of KEFJ. These mapped locations will be compared and reconciled (matched nest IDs, etc.) with the database containing historical bald eagle nests in the park in case there are nests from the last park survey in 2002 that were still extant and detected during the 2009 survey. These data also are available to be used in a dual-frame design if desired. Although we used a Trimble JunoSB for data entry during the 2009 survey, we will be developing an ArcPad 8.0 (ESRI, Inc., Redlands, CA) applet to run on a laptop for use in future surveys. This will allow the user to mark the nest location in ArcPad, which will eliminate the necessity of flying over each nest. The geodatabase with hyperlinked nest photos (Figure 7) and imagery/topographic maps will be loaded on the laptop to aid observers in relocating previously documented nests. We will work with USFWS to ensure bald eagle nest data recorded via this applet can be seamlessly added to USFWS statewide database.

An important statistical consideration for implementing the dual-frame design is ensuring that at least 40% of all nests in the survey area are contained in the list frame (i.e., known nests prior to the surveys). The dual-frame estimator loses its advantage of higher precision when the percentage of known nests falls below this level (U.S. Fish and Wildlife Service 2007). We obviously cannot know this percentage without locating all nests, but we can use the ratio of the number of detected nests and the upper 95% credible limit of the estimated total number of nests as a conservative estimate. Based on 2009 survey results ($44/101 \times 100\% = 44\%$), we are confident that we currently meet the 40% threshold even under the worst case scenario.

Independence of counts is an important aspect of the double observer method. We originally considered hanging a curtain between the front and back seats to better ensure independence, used in conjunction with light boxes to document when each observer detected a nest. However, a curtain would have obstructed more of the view of the rear-seat observer, which was already being obstructed by the fixed floats (Figure 2), and there were potential safety concerns with a curtain obstructing the pilot's peripheral view. Additionally, the lights on the light boxes were too dim for use in the helicopter. As a compromise, in the next occupancy survey we will hang a towel or similar-sized article between the front-and rear-seat observers, positioned in such a way as to obscure head movements of the two observers (left side of seat) while minimizing obstruction of the pilot's peripheral view.

The typical method for analyzing double observer data based on independent counts is to use a Lincoln-Petersen estimator (Nichols et al. 2000) or some modification thereof. Although this estimator allows for differences in nest detection probabilities (sightabilities) between observers, it assumes each nest is equally visible within observers. Violation of this equal visibility assumption (i.e., heterogeneity in detection probabilities) often arises from differences in nest characteristics and in survey conditions. We tried to adjust for this potential bias by using Bayesian hierarchical models to fit a couple of heterogeneity factors (covariates) to the detection functions for each observer. Our model selection results indicated a substantially better fit of the model including a time-of-day effect versus the Lincoln-Petersen type estimator (intercept-only model). The time-of-day covariate likely helped account for heterogeneity in sighting probabilities induced by observer fatigue and lighting/shadow conditions that occurred both during early morning and late afternoon (almost every day of the survey was sunny). The relative influence of the lighting/shadow component of this covariate will vary by weather conditions.

Low sample sizes limited how many covariates (parameters) could be reasonably fitted by the Bayesian hierarchical models. For instance, we were unable to incorporate survey day as a random effect in the detection functions because the majority of active nests were sighted during a two-day period. This imbalance in the data among days precluded a reasonably fitting model that caused an overinflated estimate of nests missed in the other five days. Low sample size is potentially a greater issue for estimating numbers of new nests under the proposed dual frame design with double observer counts. The double observer method is only applied to new active nests detected during a survey, which is very unlikely to approach the 44 nests we detected during our initial survey. Thus, our ability to model double observer data will be more restricted if we treated each survey separately. An advantage of the Bayesian modeling approach is that one can "borrow" detection functions generated in previous surveys to help model double observer data collected during a current survey, which permits lower sample sizes. However, detection functions from the same observers, or from observers with similar experience/training, should be used when combining data across surveys.

We are using number of active nests as a surrogate for territory occupancy for monitoring purposes. Assigning nests to specific territories can be very difficult because eagles may have multiple nests per territory, only one of which will be occupied during a given year. Delineating territory boundaries can be problematic even with multiple years of data. Our approach will not allow monitoring of each territory across time, although specific territories with clearly delineated boundaries (e.g., areas with low densities of nests) can be monitored individually. Two important points to keep in mind are that our estimate of active nests is based on those nests that can be detected from a helicopter (i.e., little or no availability bias) and does not reflect those nests that are occupied or initiated after the survey period.

Based on the large cost and effort required to complete a helicopter survey of bald eagle nests of the entire KEFJ coastline, we envision two potentially sustainable survey design options to meet SWAN’s objectives for monitoring nest occupancy of bald eagles in KEFJ. First, a reduced area of the park could be surveyed annually, such as the northern half of the park’s coastline from Northwestern Fjord to Bear Glacier (Figure 5). This section of the park’s coastline contains about half of the active nests detected during 2009 and represents the area of highest visitor use. Concentrating efforts on the northern half of the park’s coastline would greatly reduce flight times and costs, and would avoid the necessity to set up a fuel cache in the southern end of the park. We can use the 2009 survey results to estimate flight times and costs for assessing long-term sustainability. Second, we could annually survey nests within randomly chosen segments of the park's coastline. This would allow for a larger spatial scale of inference than option 1, including nest occupancy estimates from areas of high and low visitor use, but would require the set-up and use of a fuel cache at the southern end of the park. An option that allows inference to the entire park coastline and nearby inland areas is preferable if it is feasible. The next step is to address the costs, logistical constraints, and survey precision of this second option. We recommend the use simulations to obtain a preliminary estimate of the minimum size and number of park coastline segments that should be randomly sampled to meet monitoring objectives, followed by a nest survey in May 2010 to assess costs and survey precision.

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Appendix A: Revised Data Form for the Bald Eagle Nest Survey – Random Sample

SWAN Bald Eagle Nest Survey Data Sheet

Page _____ of ______

Date: ___________ **Park:**______________ **Recorder:** _____________________ **Pilot:** __________________________
Front Observer:____________________ (L or R) **Rear Observer:**_________________ (L or R) **Aircraft:** _______________________
(Circle Left [L] or Right [R] position in front and rear seats.)

S. Unit ID	Nest ID	Front Obs.	Rear Obs.	No. Ads.	Eagle Behav.	Nest Status	Nest Substr.	Tree Status	Tree Form	Nest Visib.	Time	Comments

Sampling (S.) Unit ID: Enter unique numeric code for the sampling unit being surveyed

Nest ID: Enter alphanumeric nest identification code (NO-#, AI-#, NW-#, OU-#, or NU-#)

Front Observer (Obs.): Enter 1 if nest was seen or 0 if nest was not seen by front observer (or Not Applicable [NA] if known nest).
Rear Observer (Obs.): Enter 1 if nest was seen or 0 if nest was not seen by rear observer (or Not Applicable [NA] if known nest).

No. of Adults (Ads.): 0, 1, 2

Eagle Behavior: Nesting (N), Flying (F), Perching (P), Nesting and Flying (NF), Nesting and Perching (NP), Not Applicable (NA)

Nest Status: Empty (E), Incubating (I), 1 Egg (1-E), 2 Eggs (2-E), 3 Eggs (3-E), 1 Young (1-Y), 2 Young (2-Y), 3 Young (3-Y)

Nest Substrate: Spruce (S), Hemlock (H), Cottonwood (C), Ground (G)
Nest Tree Status: Live (L), Dead (D), Live with Large Dead Branches (LD), Not Applicable (NA)
Nest Tree Form: Normal Top (NT), Broken Top (BR), Bushy Top (BU), Not Applicable (NA)

Nest Visibility: 1 (High visibility), 2 (Medium visibility), 3 (Low visibility)

Time Hour and minute, AM or PM

(Version 3/10/2010)

Appendix B: R2WinBUGS Code for Using Bayesian Hierarchical Models with Data Augmentation to Fit Double-observer Data and Covariates

Appendix B. The following R2WinBUGS code uses a data-augmented, Bayesian hierarchical model (Royle 2009; Biometrics 65:267-274) to fit covariates for a time-of-day, nest position in a tree, and an overdispersion term to the detection functions of both observers from double-observer data. This model can be modified to run simpler covariate models shown in Table 2. The more complex models such as the one below requires more MCMC samples, longer burn-ins and larger thinning rates than the simpler models.

```
# Specify the total number of MCMC samples (ni), the burn-in (nb), the
# thinning rate (nthin), the number of MCMC chains (nc), number of data
# augmented observations (nz) and number of nests detected (nind). The
# actual MCMC samples selected = (ni-nb)/nthin .

dobs.fn=function(ni=125000,nb=25000,nthin=20,nc=3,nz=200,nind=44){

# This function fits a "double-observer" model with individual
# covariates thought to influence detection probability. Analysis
# proceeds using data augmentation in WinBUGS. The data are the
# active bald eagle nests detected during helicopter surveys of
# the KEFJ coastline during 13-19 May 2009.  The 2 individual
# covariates thought to induce heterogeneity in detection probability
# are percent of 24-hour day at the time a nest was detected (PDay),
# and nest position in the tree (TreeP; top quarter or on ground [coded 0]
# or lower than top quarter [coded 1]). The two observers were on the left
# sides of the front and back seats of the R44 Clipper II helicopter.

library("R2WinBUGS")

# Set the working directory on your computer.

setwd("C:/Bill/Dobs_Analysis/Model_5_TreeP")

# Import the text file containing the data and specify the variables (covariates).

data<-read.table("BAEA_Nest_dat_091118.txt")
PDay<-vector(mode='numeric',length=length(data[,1]))
PDay<-data$PDay
TreeP<-vector(mode='numeric',length=length(data[,1]))
TreeP<-data$TreeP

ncap<-as.matrix(data[,1:4])

sink("model.txt")
cat("
model {
```

```
# Assign distributions to the various model parameters

psi~dunif(0,1)
psi2~dunif(0,1)
tau~dgamma(.01,.001)      # precision of normal distns

mu1.p~dunif(-6,6)
mu2.p~dunif(-6,6)
beta1~dunif(-10,10)
beta2~dunif(-10,10)

# Sample from the first 42 observations (observed nests)
# via MCMC

for(i in 1:42){
z[i]~dbin(psi,1)}

# Assign the next two observations (00 entries - nests missed by
# both observers but seen by pilot) a probability of 1 for being
# sampled via MCMC

for(i in 43:44){
z[i]~dbin(1,1)}

# Sample from the data augmented observations (obs 45-244)
# via MCMC

for(i in 45:(nind+nz)){
        z[i]~dbin(psi,1)
}

for(i in 1:(nind+nz)){

# Fit one the categorical variable with a Binomial
# distribution with 1 trial (=Bernoulli)

  TreeP[i]~dbin(psi2,1)

# Assign a uniform distribution to the continuous
# covariate PDay for the data augmented missing values

  PDay[i]~dunif(.4,.8)

# Assign normal distribution to overdispersion factor

e[i]~dnorm(0,tau)I(-5,5)
```

```
# Fit individual covariates to logit model of detection probabilities
# of two observers (next 2 lines)

  logit(p1[i])<- mu1.p + beta1*(TreeP[i]) + beta2*(PDay[i]) + e[i]
  logit(p2[i])<- mu2.p + beta1*(TreeP[i]) + beta2*(PDay[i]) + e[i]

  cp1[i]<- (1-p1[i])*p2[i]
  cp2[i]<- p1[i]*(1-p2[i])
  cp3[i]<- p1[i]*p2[i]
  cp4[i]<- (1-p1[i])*(1-p2[i])

  mu[i,1]<-z[i]*cp1[i]
  mu[i,2]<-z[i]*cp2[i]
  mu[i,3]<-z[i]*cp3[i]
  mu[i,4]<-z[i]*cp4[i] + (1-z[i])

  ncap[i,1:4]~dmulti(mu[i,1:4],1)
}

# Back transform the avg detection probs for each
# observer, evaluated at TreeP=1 and at the average
# PDay value (=0.573) (next 2 lines)

logit(p1bar)<-mu1.p + beta1 + beta2*(0.573)
logit(p2bar)<-mu2.p + beta1 + beta2*(0.573)

Nind<-sum(z[1:(nind+nz)])
}
",fill=TRUE)
sink()
data<-list("ncap","nind","nz","TreeP","PDay")
zst<-c(rep(1,nind),rbinom(nz,1,.25))
inits<-function(){
	list(mu1.p=0,mu2.p=0,beta1=rnorm(1),z=zst)
}
parameters <- c("Nind","beta1","beta2","mu1.p","mu2.p","p1bar","p2bar","psi","z")

# Specify the directory containing the WinBUGS program (bugs.directory)

out <- bugs(data, inits, parameters, "model.txt", n.thin=nthin,n.chains=nc, n.burnin=nb,n.iter=ni,
	bugs.directory="/Program Files (x86)/WinBUGS14",debug=TRUE)
out
}
dobs.fn()
```

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